

## **Quantifying Boundary Currents in the Arabian Sea**

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### **LONG-TERM GOALS**

Because they are highly variable narrow meandering jets accompanied by narrow recirculation gyres and energetic eddy fields, estimating the velocity and volume transport of western boundary currents (WBCs) poses significant challenges. In the case of the WBC of the Arabian Sea, the difficulty is compounded because of seasonally reversing monsoon winds. A challenge for a transport array is the need to fully span the connecting current systems in order to understand the dynamics, structure and variability of the northern Arabian Sea WBC.

Recent analyses have shown that observational approaches that include data from multi-platforms (i.e. XBTs, Argo floats, altimetry etc.) may reduce errors in estimates of oceanic volume transport. This is because individual components of the observing system all have limitations when it comes to obtaining accurate observations with sufficiently fine resolution to resolve the flow field in space and time along the narrow path of the WBC system.

The long-term goal is to produce an index of transport variability in the WBC system of the northern Arabian Sea using combined complementary modern data sets. The effort will focus on merging available high-density XBT transects with Argo float profiles and trajectories and altimetric data sets to characterize the spatial and temporal variability of the circulation in the northern Arabian Sea.

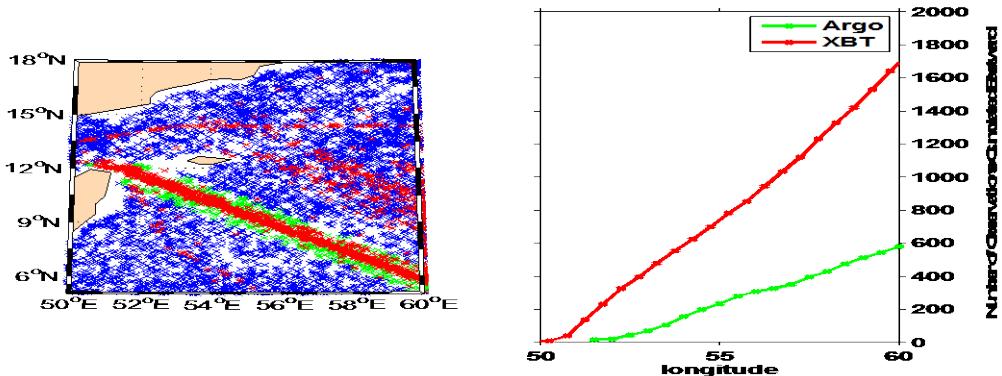
### **OBJECTIVES**

The scientific goal of the proposed effort is to observe and understand the processes that govern the flow in the WBC system and its relationship to the monsoonal winds and air-sea forcing. Specifically the main scientific research objectives are to:

- (1) Obtain estimates and their errors of the upper ocean volume transport in the WBC system of the Arabian Sea on seasonal to interannual time scales;
- (2) Identify the main forcing mechanisms that control the transport variability of the Somali Current and the exchange and partitioning between the contiguous current systems.

## APPROACH

Estimates of the absolute mean and seasonal to interannual variability in geostrophic transport (0-2000 m) of the WBC current system in the Arabian Sea will be obtained by combining High Resolution XBT (HRX) transects, Argo profile and trajectory data and satellite altimetry. Figure 1 shows the Argo float distribution (2004-2014) in the Arabian Sea and the XBT data from one of the HRX transects in the Arabian Sea IX12 (1987-2014). Clearly the Argo float density close to the coast will not be sufficient to capture the narrow jets associated with the WBC that are well sampled by the HRX profiles. The strategy is that the HRX transects will be merged with Argo float profiles and trajectories to expand HRX shear estimates from the typical XBT probe depth of ~800 m to 2000-m using the Argo shear and trajectory reference level velocity. This technique produces absolute geostrophic velocity and the associated transport. The HRX data are central in this exercise since the close spacing of the probes (typically 20-30 km) does a much better job of resolving the near-surface velocity shear in the narrow boundary currents. HRX/Argo data will also be combined with altimetric datasets to correct for uncertainties generated by unresolved mesoscale activity in HRX measurements. WBC transport variability will also be addressed using combined altimetry/HRX/Argo data and multi-regression techniques that have proven to produce highly accurate and successful transport proxies in other swift, narrow current systems.



**Figure 1: Left Panel:** Data density of XBT data nominally along IX12 (red x) and all Argo floats in Arabian Sea (blue x) and Argo floats within  $\pm 2$  degrees of the nominal IX12 transect (green x). **Right Panel:** Cumulative number of XBT (red) and Argo floats (green) along IX12 to be used in transport calculations.

This project will make use of existing HRX transect data, currently maintained by the Australian Bureau of Meteorology and CSIRO DMAR. In particular, the focus will be on transect IX12 from Fremantle to the Red Sea, which has been regularly occupied (~7-10 times per year) since 1987, and continues to be actively sampled with 404 XBT probes deployed in 2014. Other transects include the IX10 zonal transect from Sri Lanka to the Gulf of Aden, as well as periodic occupations of the IX07 meridional transect along the east coast of Africa up to the Gulf of Aden. We propose to use the Argo data to provide the (800-2000 m) geostrophic shear to expand the HRX 0-800 m shear, and compute absolute velocity computations assuming a 2000- m level of no motion, as well as using the Argo trajectory fields to derive a reference velocity from the parking depth at 2000 m. The altimetric data will primarily be used to resolve the mesoscale variability of the boundary jet.

## WORK COMPLETED

During this past year, I attended and presented at the NASCar Planning Meeting, held in Reston, VA, 1-3 June 2015. The purpose of the meeting was to combine individual PI science objectives and activities into an integrated science plan, with programmatic objectives and an integrated set of observations, modeling and analyses. Subsequently the science and science objectives are being written up as a science plan, and the experiment and operation plan in an implementation plan. I actively participated in the meeting to develop the science questions, and am a member of the Western Boundary Dynamics team and the Upper Ocean Dynamics of the Interior Arabian Sea team.

All XBT data from 1986 through 2014 along IX12 have now been obtained from the Bureau of Meteorology. Initial efforts have concentrated on quality control of the data, and organizing the individual profiles into transects to produce a time series. Next I will focus on resolving the spatial decorrelation scales from the geostrophic transport and altimetry measurements that are needed to adequately resolve the boundary current system of the Arabian Sea. This effort will also provide vital information for the DRI as to where additional sampling might be needed through field deployments.

## RESULTS

The mean temperature section along IX12 shows the thermocline becomes spread and elevated near the African coast, supporting a mean northward Somali Current, although there is high variability of  $>1.5^{\circ}\text{C}$  centered around 150 m depth. This result emphasizes the need for resolving the seasonality of the boundary current system which is known to reverse in response to monsoonal wind variability. The current system is found to vary considerably in strength, vertical profile and pathway over the complete annual cycle.

## IMPACT/APPLICATIONS

The mechanisms responsible for the spatial structure, strength and variability of the Somali Current system remain largely indeterminate. Early studies suggested the initial development of the Arabian Sea WBC system during the summer monsoon was due to remote wind forcing setting up a Sverdrupian response, with local wind stress then responsible for establishing and sustaining the Somali Current throughout the remaining monsoon period. However recent analysis of drifter and satellite data suggests that the initial reversal that occurs well before the onset of the southwest monsoon is most likely in response to the arrival of annual Rossby waves that radiate from the southern tip of India. On the other hand, local wind variability and boundary current detachment/instability has also been suggested as playing a major role in setting up the Somali Current. Unquestionably the semi-annual monsoon winds strongly influence the strength, direction and variability of the currents and semi-permanent eddies of the boundary current system during their peak phase. The phase and strength of the monsoon vary from year to year and this will rectify the seasonal and intraseasonal variability in a way that is not well understood at present. Clearly the complex balance between the local and remote wind forcing and the role they each play in the evolution of the Arabian Sea WBC system deserve further attention. Ultimately, this will enable a better representation and prediction in numerical and theoretical models of the structure and evolution of the circulation in this region, including the time-dependent variability.

## RELATED PROJECTS

I am working directly with other DRI investigators, particularly those deploying Argo floats (Riser, Talley, Jayne), observationalists who are also interested in boundary currents (Lee, Centurioni, Beal) and modellers (McClean) to help provide context for the observations and understanding the mechanisms responsible for transport variability. As part of the “Upper Ocean Dynamics of the Interior Sea” task team, led by Andrey Scherbina, I am developing climatologies from the Argo and XBT data sets.